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Nutrient losses in runoff from feedlot surfaces as affected by unconsolidated surface materials

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Abstract: Beef cattle feedlots contain unconsolidated surface materials (loose manure pack) that accumulate during a feeding cycle. The effects of varying amounts of unconsolidated surface materials on runoff nutrient losses are not well understood. The objectives of this study were to (1) compare runoff nutrient losses from feedlot surfaces containing varying amounts of unconsolidated surface materials, (2) determine if differences in runoff nutrient losses exist among rainfall simulation runs, (3) relate runoff nutrient losses to selected feedlot soil characteristics, and (4) identify the effects of varying runoff rate on nutrient loss rates from feedlot surfaces. This study was conducted on 0.75 m wide by 2 m long (2.47 ft wide by 6.58 ft long) plots containing 0, 6.7, 13.5, or 26.9 kg m^{-2} (0, 1.37, 2.77, or 5.51 lb ft^{-2}) of unconsolidated surface materials. Simulated rainfall was applied during three 30-minute events that were separated by 24-hour intervals. Inflow was added at the top of all plots during selected tests to examine the effects of varying flow rate on nutrient loss rates. No significant differences in the measured water quality parameters were found among the surfaces containing varying amounts of unconsolidated surface materials. Measurements of dissolved phosphorus, particulate phosphorus, total phosphorus, ammonium nitrogen, chloride, total dissolved solids, electrical conductivity, and erosion consistently decreased during the three rainfall simulation runs. Runoff losses of ammonium nitrogen (NH_4-N), total nitrogen, and nitrate nitrogen were all correlated to easily obtained soil EC measurements. All measured water quality parameters were significantly influenced by runoff rate. Thus, runoff rate, and not the amount of unconsolidated surface materials on the feedlot surface, significantly influenced nutrient losses in runoff.

Key words: beef cattle—feedlots—manure management—manure runoff—nutrient losses—water quality

Beef cattle feedlots contain unconsolidated surface materials (loose manure pack) that accumulate during a feeding cycle. The amount of unconsolidated surface materials on a feedlot surface may vary substantially depending on the time since pen cleaning, pen location, and length of time since the most recent precipitation event. A black interface layer of consolidated subsurface materials is maintained below the unconsolidated surface materials to enhance surface runoff and limit infiltration, thus helping to reduce wet feedlot conditions (Mielke et al. 1974; Mielke and Mazurak 1976). Mounds constructed of soil material within feedlot pens provide a comfortable place for cattle to stand or lay during prolonged wet periods. Mounds are an economical alternative to bedding, concrete lots, or confinement buildings.

Manure is typically removed from a feedlot between cattle production cycles, usually once or twice a year. Fill material, which usually consists of soil from an area near the feedlot, is often used to return the feedlot pen to original grade and elevation following removal of both the unconsolidated surface materials and consolidated subsurface materials (Woodbury et al. 2001). Equipment used for feedlot manure removal following a feeding cycle could also be used to remove unconsolidated surface materials that accumulate during the feeding cycle.

Bedding and within-pen location effects on feedlot runoff quality in southern Alberta, Canada were examined by Miller et al. (2006). Pen location had a significant effect on electrical conductivity (EC) and concentrations of chloride (Cl), potassium, sodium, and total nitrogen (TN). The physical and chemical characteristics of runoff from beef cattle feedlots were influenced by animal age and condition, animal density and size, climate, diet, feedlot surface conditions, handling and storage of manure, and soil type. Gilley et al. (2008) measured nutrient losses in runoff from selected feedlot locations and compared the effects of unconsolidated surface materials and consolidated subsurface materials on runoff nutrient losses. No significant differences in nutrient losses were found between unconsolidated surface materials and consolidated subsurface materials. Runoff measurements of dissolved phosphorus (DP), EC, and ammonium nitrogen (NH_4-N) were significantly influenced by pen location.

Nutrient losses in runoff from surfaces amended by pond ash and traditional soil surfaces were compared by Gilley et al. (2009). Runoff losses of NH_4-N were significantly greater on the pond ash amended surfaces, while losses of total phosphorus (TP) were significantly greater on soil surfaces. Runoff losses of nitrate nitrogen (NO_3-N) and TN were significantly greater on the feedlot surfaces containing consolidated subsurface materials.

Unconsolidated surface materials are thought to be a source of feedlot dust (Miller and Woodbury 2003). Maximum dust potential and airborne residence time vary among pen locations. The frequent removal of unconsolidated surface materials has been suggested as a best management practice for feedlot dust control. The amount of unconsolidated surface materials on a feedlot surface may influence nutrient losses in runoff. The relative contributions of unconsolidated surface materials and consolidated subsurface materials to nutrient losses in

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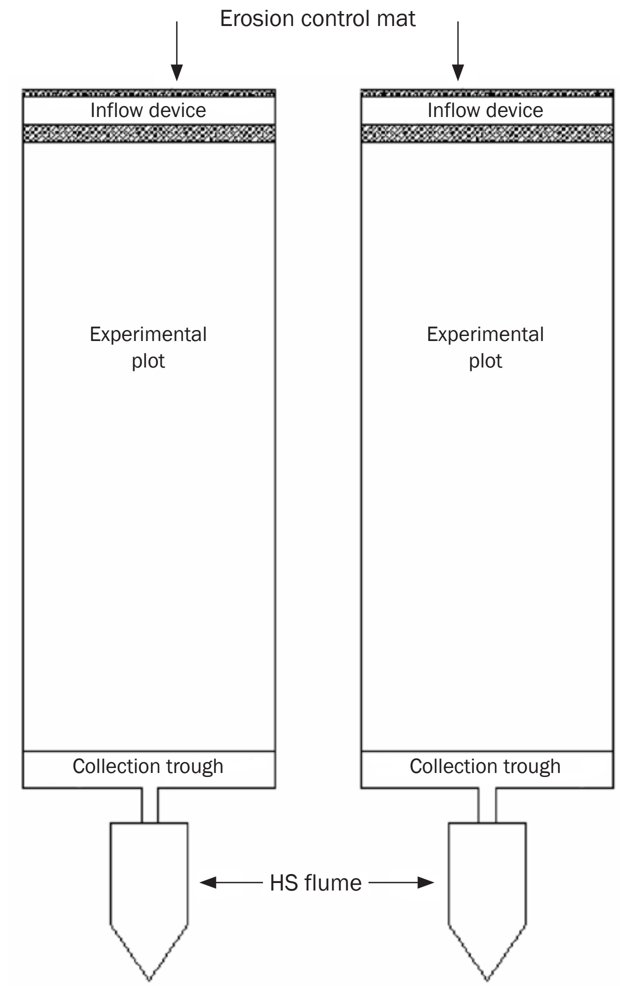
runoff are not well understood. The source of potential contaminants must be identified before acceptable practices for managing feedlot runoff can be adopted. The runoff water quality implications of the periodic removal of unconsolidated surface materials from a feedlot surface will be examined in this investigation.

The objectives of this study were to (1) compare runoff nutrient losses from feedlot surfaces containing varying amounts of unconsolidated surface materials, (2) determine if differences in runoff nutrient losses exist among rainfall simulation runs, (3) relate runoff nutrient losses to selected feedlot soil characteristics, and (4) identify the effects of varying runoff rate on nutrient loss rates from feedlot surfaces.

Figure 1

Schematic showing a pair of experimental plots, inflow devices, collection troughs, and HS flumes.



Materials and Methods

Study Site Description. This study was conducted at the US Meat Animal Research Center near Clay Center, Nebraska within four 30 × 60 m (98 × 197 ft) pens constructed on a Hastings silt loam soil (fine, smectitic, mesic Pachic Argiustolls). Steers were placed in the feedlot at a rate of 36 head per pen and fed a corn-based diet. Livestock within an individual pen were removed just prior to plot establishment, and they remained outside the pen for the duration of the testing period.

The study sites were established in upslope pen locations on the side of a mound with a mean slope gradient of 10.5%, which allowed overland flow to drain uniformly from the experimental plots. The mounds were built with soil excavated from the C-horizon of a Hastings silt loam soil located off-site. Four adjoining 0.75 × 2 m (2.47 × 6.58 ft) plots were placed within each of the pens. Thus, a total of 16 plots were examined (4 pens with 4 surface conditions per pen).

All of the unconsolidated surface materials were removed from one of the four adjoining plots within each pen to create the surface containing consolidated subsurface materials. The feedlot surface containing approximately 6.7 kg m^{-2} (1.37 lb ft^{-2}) of unconsolidated surface materials remained undisturbed on a second plot. The unconsolidated surface materials were first removed and then replaced at rates of 13.5 or 26.9 kg m^{-2} (2.77 or 5.51 lb ft^{-2}) on the other two plots within each pen. These rates were approximately two and four times larger than the amounts found on the undisturbed plot. The unconsolidated surface materials placed on the plots were obtained from an undisturbed area within the pen at a similar down-slope location.

Collection and Analyses of Feedlot Soil Materials. The mass of unconsolidated surface materials on selected plots was measured on site. A sample of the unconsolidated surface materials was obtained and stored in a cooler at 4°C (39°F) for subsequent analyses. Feedlot soil samples were obtained from the outside perimeter of each of the four test plots with surfaces containing consolidated subsurface materials. A small shovel was used to obtain the samples from a depth of approximately 0 to 1.5 cm (0 to 0.6 in) (after the unconsolidated surface materials had been removed). Composite samples of unconsolidated surface materials or consolidated subsurface materials were sent to a commercial laboratory and analyzed for calcium, Cl, copper, EC, iron, magnesium, manganese, NH_4-N, organic-N, pH, phosphorus (P), potassium, sodium, sulfur, TN, water content, and zinc. Electrical conductivity and pH were measured in a 1:5 soil: water ratio.

Organic matter content was measured by loss on ignition (Nelson and Sommers 1996). Soil NO_3-N concentrations (extracted using a 2 molar potassium chloride solution) were determined with a flow injection analyzer using spectrophotometry (Lachat system from Zellweger Analytics, Milwaukee, Wisconsin). Water-soluble P in solution was measured by shaking 2 g (0.07 oz) of soil for 5 minutes with 20 ml (0.68 oz) of deionized water, using the Murphy and Riley (1962) procedure. An indicator of the availability of soil P for the growth of plants was also measured (Bray and Kurtz 1945).

Table 1
Effects of surface condition on selected soil characteristics.

Surface condition	USM	CSM
Bray 1 phosphorus (mg kg^{-1})	692a	632b
Calcium (g kg^{-1})	15.5b	19.6a
Chloride (g kg^{-1})	1.5	2.5
Copper (mg kg^{-1})	34b	38.9a
Electrical conductivity (dS m^{-1})	7.9	11.7
Iron (mg kg^{-1})	14,500	15,000
Loss on ignition (g kg^{-1})	288	296
Magnesium (g kg^{-1})	7.2b	8a
Manganese (mg kg^{-1})	284	284
Ammonium nitrogen (g kg^{-1})	0.03	0.02
Nitrate nitrogen (mg kg^{-1})	0.03	0.02
Organic nitrogen (g kg^{-1})	14.7	14.3
pH	8.2b	8.4a
Phosphorous (g kg^{-1} P_2O_5)	12.6	12.4
Potassium (g kg^{-1} K_2O)	13.6	15.3
Sodium adsorption ratio	2.51	3.24
Sodium (g kg^{-1})	1.5	2.2
Sulfur (g kg^{-1})	3.5a	3.1b
Total nitrogen (g kg^{-1})	14.9	15.2
Water content (g kg^{-1})	149	265
Water soluble phosphorus (mg kg^{-1})	160	161
Zinc (mg kg^{-1})	127	130

Notes: USM = unconsolidated surface materials. CSM = consolidated subsurface materials. Values followed by different letters are significantly different at the 0.05 probability level based on the least significant difference test.

Rainfall Simulation Procedures. Water used in the rainfall simulation tests was obtained from a groundwater well near the feedlot complex. The reported nutrient concentrations represent the difference between runoff measurements and nutrient content of applied water. Measured mean concentrations of DP, NO_3-N, and NH_4-N in the well water were 0.13, 3.2, and 0.04 mg L^{-1} (0.13, 3.2, and 0.04 ppm), respectively.

Rainfall simulation procedures adopted by the National Phosphorus Research Project were employed in this study (Sharpley and Kleinman 2003). Plot borders consisted of prefabricated sheet metal boundaries enclosing three sides of each plot and a sheet metal lip located at the bottom that emptied into a collection trough. The trough extended across the plot and diverted runoff into plastic drums. Two rain gauges were placed along the outer edge of each plot, and one rain gauge was located between the plots.

A portable rainfall simulator based on the design by Humphry et al. (2002) was used to apply rainfall simultaneously to paired plots. The rainfall simulator operated for 30 minutes at intensity of approximately 70 mm h^{-1} (2.8 in hr^{-1}). A storm in this area with this intensity and duration has approximately a five-year recurrence interval (Hershfield 1961). Two additional rainfall simulation runs were conducted for the same duration and intensity at approximately 24-hour intervals.

The plastic drums were weighed to determine total runoff volume after completion of each of the three rainfall simulation runs. Runoff samples were then obtained for water quality and sediment analyses. Runoff that was collected within the plastic drums was discarded after each precipitation event.

The samples obtained for sediment analysis were dried in an oven at 105°C (221°F) and then weighed to determine sediment concentration. Centrifuged and filtered runoff samples were analyzed for DP (Murphy and Riley 1962), NO_3-N, and NH_4-N using a Lachat system (Zellweger Analytics, Milwaukee, Wisconsin). Noncentrifuged samples were analyzed for Cl, EC, pH, total dissolved solids (TDS), TN (Tate 1994) and TP (Johnson and Ulrich 1959). The difference between measurements of TP and DP was reported as particulate phosphorus (PP).

Additional testing was conducted to identify the effects of varying flow rates on nutrient losses. The addition of inflow to the test plots to simulate greater slope length is a well-established experimental procedure (Monke et al. 1977; Laflen et al. 1991). After the first 30 minutes of the third simulation run, runoff was diverted into a 0.18 m (0.59 ft) HS flume on which a stage recorder was mounted to measure runoff rate (figure 1). Rainfall continued during the inflow tests.

A 2.5 cm (1 in) diameter plastic tube that extended across the top of the plot served as an inflow device. Several holes were drilled into the plastic tube to allow water to be introduced uniformly across the plot surface. A gate value and associated pressure gauge located on the inflow device were adjusted to provide the desired flow rate. Inflow was added in four successive increments to produce average runoff rates of 5, 8.4, 9.7, and 15.3 L min^{-1} (1.3, 2.2, 2.6, and 4 gal min^{-1}). Runoff and erosion measurements obtained during the 30 minutes before the addition of inflow were included in the analyses.

A mat consisting of material typically used for an outdoor carpet was placed on the soil surface beneath the inflow device to prevent scouring and to distribute the flow more uniformly across the plot (figure 1). Flow addition for each inflow increment usually occurred for approximately eight minutes. This was the period of time typically required for steady-state flow conditions to become established and samples for nutrient and sediment analyses to be collected.

Statistical Analyses. Statistical analyses were conducted using the Mixed Procedures of SAS (SAS 2003) (ANOVA). Differences among treatment means were determined using the least significant difference (LSD) test. A probability level <0.05 was considered significant. ANOVA and LSD tests have been used in previous rainfall simulation studies to successfully identify significant differences among treatment means. Correlation analysis was used to examine the relationship between runoff nutrient transport and chemical and physical characteristics of the feedlot soil materials.

Results and Discussion

Feedlot Soil Properties. The concentration of Bray 1-P was significantly greater for surfaces with unconsolidated surface materials than consolidated subsurface materials as shown in table 1. The manure on the feedlot surface

Table 2
Effects of varying amounts of unconsolidated surface materials on selected runoff characteristics.

Amount of USM and simulation run	DP (kg ha^{-1})	PP (kg ha^{-1})	TP (kg ha^{-1})	NO_3-N (kg ha^{-1})	NH_4-N (kg ha^{-1})	TN (kg ha^{-1})	Cl (kg ha^{-1})	TDS (kg ha^{-1})	EC (dS m^{-1})	pH	Runoff (mm)	Erosion (Mg ha^{-1})
Amount of USM (kg m^{-2})												
0	0.98	0.85	1.84	0.64	2.33	3.35	62.6	374	1.90	7.67	22.5	0.65
6.7	1.32	1.11	2.43	0.94	3.39	4.99	73.7	475	2.38	7.66	22.0	0.57
13.5	1.72	0.60	2.31	2.50	1.15	6.45	60.5	458	2.34	7.74	19.7	0.46
26.9	1.65	0.59	2.24	2.17	1.31	4.83	52.4	313	2.54	7.70	14.3	0.45
Simulation run												
1	1.72a	1.05a	2.77a	1.64	2.89a	4.63	83.6a	542a	2.66a	7.63	19.7	0.63a
2	1.31b	0.73b	2.03b	1.81	1.99ab	4.55	60.3a	384a	2.33a	7.72	19.5	0.53ab
3	1.22b	0.59b	1.81b	1.23	1.26b	5.53	43.0b	289b	1.87b	7.72	19.7	0.43b
Analysis of variance (Pr > F)												
Amount of USM	0.55	0.60	0.92	0.16	0.34	0.73	0.84	0.69	0.71	0.34	0.46	0.74
Simulation run	0.01	0.01	0.01	0.06	0.01	0.57	0.01	0.01	0.01	0.07	0.99	0.01
Amount of USM × simulation run	0.26	0.24	0.21	0.17	0.33	0.57	0.70	0.25	0.75	0.83	0.43	0.37

Notes: USM = unconsolidated surface materials. DP = dissolved phosphorus. PP = particulate phosphorus. TP = total phosphorus. NO_3-N = nitrate nitrogen. NH_4-N = ammonium nitrogen. TN = total nitrogen. Cl = chloride. TDS = total dissolved solids. EC = electrical conductivity. Values followed by different letters are significantly different at the 0.05 probability level based on the least significant difference test.

(unconsolidated surface materials) may have been more readily mineralized, resulting in the larger Bray 1-P concentrations obtained for the unconsolidated surface materials. In contrast, concentrations of calcium, copper, magnesium, and pH were significantly greater for the consolidated subsurface materials. Calcium, copper, and magnesium in the unconsolidated surface materials may have leached into the consolidated subsurface materials, resulting in significantly greater concentrations in the subsurface materials.

Gilley et al. (2008) found that there were no significant differences in feedlot soil concentrations between unconsolidated surface materials and consolidated subsurface materials collected at different locations within a beef cattle feedlot. The mean water content of the unconsolidated surface materials measured by Gilley et al. (2008) was 176 g kg^{-1} (352 lb tn^{-1}) compared to 265 g kg^{-1} (530 lb tn^{-1}) obtained in the present investigation. The occurrence of recent precipitation during the present investigation may have enhanced mineralization of P in the unconsolidated surface materials and caused greater quantities of some chemical constituents to have leached into the consolidated subsurface materials.

The presence of calcium carbonate in the manure is thought to have caused the relatively high mean pH value of 8.3 for feedlot soil materials. The mean sodium adsorption ratio of 2.88 would have been expected to have been larger if calcium carbonate was not present in the manure. Calcium carbonate is commonly added to cattle diets as a source of calcium (Klemesrud et al. 1998). Much of the calcium carbonate contained in the diet is excreted in the manure. The pH of soils where manure is applied can increase (become more basic) as a result of land application (Eghball 1999).

Feedlot Runoff Results. There were no significant interactions between unconsolidated surface materials and simulation run for any of the measured water quality parameters (table 2). Specific yields of DP, TP, NO_3-N, TN, and EC were greater for the feedlot surfaces containing unconsolidated surface materials than the surfaces with consolidated subsurface materials, but the differences were not statistically significant. In addition, no significant differences in specific yields were found among the three treatments containing varying amounts of unconsolidated surface materials. Larger P losses were expected on the feedlot surfaces containing consolidated subsurface materials because soil concentrations of Bray 1-P were greater on those surfaces. However, there was more surface area available for P to be desorbed on the surfaces with unconsolidated surface materials, which may have resulted in the larger nutrient loads for P on the surfaces containing unconsolidated surface materials.

The feedlot surfaces contained relatively large amounts of nutrients. Reducing the amount of unconsolidated surface materials on the feedlot surface did not significantly influence nutrient loads. Thus, the frequent removal of unconsolidated surface materials from a feedlot would not appear to significantly affect runoff nutrient loads.

In this study, mean runoff and erosion measurements on the feedlot surfaces were 20 mm (0.79 in) (approximately 35 mm [1.38 in] of rainfall was applied) and 0.53 Mg ha^{-1} (473 lb ac^{-1}), respectively. Gilley et al. (2007) measured runoff and erosion from a cropland site during the year following application of beef cattle manure. Under tilled conditions, runoff and erosion values were 23 mm (0.91 in) and 0.52 Mg ha^{-1} (464 lb ac^{-1}), respectively (approximately 35 mm [1.38 in] of rainfall was applied). Thus, the quantities of runoff and erosion from the feedlot and tilled cropland sites were similar.

Measurements of DP, PP, TP, NH_4-N, Cl, TDS, EC, and erosion consistently decreased during the three rainfall simulation runs. Values for each of these constituents were significantly greater during the initial rainfall simulation run than the third rainfall simulation event. The initial rainfall simulation tests were conducted soon after the cattle had been removed from the feedlot. The largest potential for nutrient losses appears to exist on recently deposited manure where previous precipitation has not occurred.

Correlation Analyses. The PP losses in runoff were significantly correlated to nine feedlot soil properties (table 3). Both NH_4-N and NO_3-N losses, in turn, were significantly correlated to the same seven

Table 3

Correlation coefficients of soil characteristics with runoff characteristics.

Runoff characteristic	DP	PP	TP	NH_4-N	Total N	Cl	NO_3-N	TDS	EC	pH
Bray 1-P	0.41 (0.12)	−0.32 (0.22)	0.14 −0.6	−0.38 (0.15)	0.12 (0.67)	−0.34 (0.2)	0.28 (0.3)	−0.42 (0.11)	0.23 (0.38)	−0.42 (0.11)
Calcium	−0.48 (0.06)	**0.56 (0.02)**	−0.08 −0.76	**0.65 (0.01)**	−0.47 (0.07)	0.43 (0.1)	**−0.6 (0.01)**	0.45 (0.08)	0.11 (0.68)	0.17 (0.52)
Cl	−0.38 (0.15)	**0.67 (0.01)**	0.05 −0.87	**0.6 (0.01)**	**−0.59 (0.02)**	0.34 (0.19)	**−0.71 (0.01)**	0.34 (0.19)	0.28 (0.29)	−0.11 (0.67)
Copper	−0.43 (0.1)	**0.58 (0.02)**	−0.03 −0.9	**0.73 (0.01)**	−0.49 (0.05)	0.47 (0.07)	**−0.61 (0.01)**	0.42 (0.1)	0.22 (0.41)	0.13 (0.64)
EC	−0.3 (0.26)	**0.63 (0.01)**	0.09 −0.75	**0.55 (0.03)**	**−0.61 (0.01)**	0.3 (0.27)	**−0.7 (0.01)**	0.22 (0.42)	0.36 (0.17)	−0.26 (0.32)
Iron	−0.17 (0.53)	−0.4 (0.13)	−0.32 −0.23	−0.18 (0.5)	0.37 (0.16)	−0.1 (0.71)	0.19 (0.49)	−0.04 (0.87)	**−0.78 (0.01)**	0.33 (0.22)
Loss on ignition	0.12 (0.66)	0.39 (0.13)	0.28 −0.29	0.29 (0.27)	−0.40 (0.13)	0.18 (0.5)	−0.22 (0.42)	0.2 (0.47)	**0.64 (0.01)**	−0.15 (0.58)
Magnesium	−0.41 (0.12)	**0.61 (0.01)**	−0.01 (0.49)	**0.64 (0.01)**	−0.4 (0.13)	0.43 (0.1)	**−0.56 (0.02)**	0.49 (0.06)	0.03 (0.9)	0.12 (0.66)
Manganese	0.25 (0.35)	**−0.61 (0.01)**	−0.11 (0.68)	−0.47 (0.07)	0.47 (0.07)	−0.38 (0.15)	0.48 (0.06)	−0.42 (0.11)	−0.41 (0.11)	0.09 (0.73)
NH_4-N	−0.29 (0.27)	**0.56 (0.02)**	0.06 (0.83)	0.41 (0.11)	−0.37 (0.16)	0.23 (0.38)	−0.49 (0.05)	0.31 (0.24)	0.04 (0.9)	−0.17 (0.52)
NO_3-N	0.14 (0.62)	−0.48 (0.06)	−0.13 (0.63)	−0.34 (0.2)	0.28 (0.3)	−0.28 (0.29)	0.48 (0.06)	−0.27 (0.31)	−0.16 (0.56)	**0.52 (0.04)**
Organic N	0.23 (0.39)	0.38 (0.14)	0.36 (0.17)	0.39 (0.13)	−0.24 (0.36)	0.22 (0.42)	−0.14 (0.61)	0.12 (0.65)	**0.75 (0.01)**	**−0.53 (0.04)**
pH	−0.4 (0.13)	0.28 (0.29)	−0.16 (0.56)	0.44 (0.09)	−0.18 (0.50)	0.35 (0.18)	−0.34 (0.2)	0.31 (0.25)	−0.24 (0.38)	0.48 (0.06)
Phosphorous	0.05 (0.86)	−0.09 (0.75)	−0.01 (0.98)	−0.06 (0.84)	−0.3 (0.27)	−0.17 (0.54)	−0.06 0.82	−0.25 (0.35)	**0.57 (0.02)**	−0.32 (0.23)
Potassium	−0.03 (0.9)	0.44 (0.09)	0.19 (0.48)	0.39 (0.13)	−0.42 (0.11)	0.15 (0.59)	−0.47 (0.07)	0.03 (0.90)	0.36 (0.17)	−0.37 (0.16)
SAR	−0.22 (0.41)	**0.72 (0.01)**	0.19 (0.49)	**0.69 (0.01)**	**−0.57 (0.02)**	0.46 (0.07)	**−0.64 (0.01)**	0.37 (0.16)	0.48 (0.06)	−0.21 (0.44)
Sodium	−0.31 (0.25)	**0.73 (0.01)**	0.13 (0.63)	**0.73 (0.01)**	**−0.55 (0.03)**	0.49 (0.05)	**−0.66 (0.01)**	0.44 (0.09)	0.38 (0.15)	−0.11 (0.68)
Sulfur	−0.12 (0.67)	−0.1 (0.71)	0.04 (0.89)	−0.06 (0.83)	−0.03 (0.90)	0.09 (0.73)	0.21 (0.44)	0.11 (0.69)	0.38 (0.15)	−0.03 (0.92
Total N	0.15 (0.57)	0.48 (0.06)	0.35 (0.18)	0.46 (0.08)	−0.31 (0.24)	0.25 (0.36)	−0.24 (0.38)	0.18 (0.51)	**0.71 (0.01)**	**−0.53 (0.03)**
Water content	−0.33 (0.21)	0.46 (0.07)	−0.02 (0.94)	0.49 (0.05)	−0.42 (0.10)	0.06 (0.83)	**−0.57 (0.02)**	0.14 (0.61)	−0.03 (0.91)	−0.33 (0.21)
Water soluble P	0.25 (0.34)	−0.09 (0.73)	0.14 (0.6)	−0.15 (0.58)	−0.17 (0.54)	−0.24 (0.36)	−0.01 (0.99)	−0.33 (0.22)	0.41 (0.11)	−0.41 (0.11)
Zinc	−0.09 (0.74)	0.42 (0.11)	0.14 (0.61)	**0.58 (0.02)**	−0.4 (0.13)	0.32 (0.22)	−0.39 (0.13)	0.18 (0.5)	**0.58 (0.02)**	−0.16 (0.56)

Notes: DP = dissolved phosphorus. PP = particulate phosphorus. TP = total phosphorus. NO_3-N = nitrate nitrogen. NH_4-N = ammonium nitrogen. Total N = total nitrogen. Cl = chloride. TDS = total dissolved solids. EC = electrical conductivity. SAR = sodium adsorption ratio. A correlation coefficient is significant at the 95% level (shown in **bold**) if correlation coefficient (*r*) > 0.5 for n = 16. Values in parentheses represent the probability > *r*.

soil properties. In comparison, specific yields of DP, TP, Cl, and TDS were not significantly correlated to any of the measured feedlot soil characteristics.

Runoff losses of DP or TP were not significantly correlated to feedlot soil concentrations of Bray 1-P or water soluble P. The loss of P in runoff may have been influenced by P desorption kinetics. The amount of P in runoff may have been limited by the contact time between the runoff and the feedlot surface, not the amount of unconsolidated surface materials on the feedlot surface. Therefore, increased amounts of P on the feedlot surface would be expected to have little impact on specific yields of DP or TP.

Runoff losses of NH_4-N and TN were not significantly correlated to feedlot surface concentrations of NH_4-N, organic N, or TN. Again, the quantities of N found on the feedlot surface were thought to be much larger than the amount that could be lost in runoff. However, the specific yields of NH_4-N, TN, and NO_3-N in runoff were all correlated to soil EC measurements. Therefore, it may be possible to estimate runoff N losses from easily obtained measurements of soil EC.

Runoff Characteristics as Affected by Inflow. Separate statistical analyses were performed for the experimental tests conducted with and without the addition of inflow. There were no significant interactions between unconsolidated surface materials and runoff rate for any of the measured water quality parameters (table 4). For the inflow tests, the interaction between the amount of unconsolidated surface materials and the runoff rate was not significant for any of the measured water quality parameters (table 4). The water quality parameters also were not significantly affected by varying amounts of unconsolidated surface materials. The same experimental results were obtained for the tests conducted without the addition of inflow (table 2).

Each of the measured water quality parameters were significantly influenced by runoff rate (table 4). The specific yield rates for DP and TP ranged from 21.6 to 105 g ha^{-1} min^{-1} (0.0242 to 0.118 lb ac^{-1} min^{-1}) and 26.9 to 134 g ha^{-1} min^{-1} (0.0301 to 0.150 lb ac^{-1} min^{-1}), respectively (table 4). No significant differences in specific yield rates for DP or TP were found for runoff rates 5 L min^{-1} (1.3 gal min^{-1}) and larger. Specific yield rates for PP ranged from 5.3 to 28.7 g ha^{-1} min^{-1} (0.0059 to 0.0321 lb ac^{-1} min^{-1}), which was smaller than the rates measured for DP and TP.

A relatively large concentration of P is contained in feedlot surface materials (table 1). It can be assumed that two important variables influencing rates of P loss are the rates of P desorption and P nutrient load capacity. The amount of P that is lost in runoff at the lower flow rates may be influenced by P nutrient load capacity. However, once P nutrient load capacity exceeds rate of P desorption, rate of P desorption becomes the controlling variable, and P losses becomes nearly constant.

It appears that the NO_3-N and TN contained on the feedlot surface is highly soluble and readily removed by overland flow since the nutrient load rates for NO_3-N and TN increased in linear fashion with flow rate and ranged from 1.3 to 510 g ha^{-1} min^{-1} (0.0015

Table 4

Runoff water quality parameters as affected by rate of unconsolidated surface materials and runoff rate.

Variable	DP	PP	TP	NO_3-N	NH_4-N	TN	Cl	TDS	EC ($dS\ m^{-1}$)	pH	Soil loss ($kg\ ha^{-1}\ min^{-1}$)
	Nutrient constituent ($g\ ha^{-1}\ min^{-1}$)										
Rate of USM ($kg\ m^{-2}$)											
0	48.5	31.2	79.7	185	62.4	366	1,460	36,800	0.8	7.73	75.7
6.7	72.8	24.1	96.9	202	76.4	436	2,090	35,600	0.9	7.72	34.9
13.5	92.8	9.8	103	291	68.4	484	1,770	53,400	0.94	7.72	38.7
26.9	141	7.9	148	320	75.1	576	2,100	34,700	1.03	7.68	47.3
Runoff rate ($L\ min^{-1}$)											
0.5	21.6b	5.3c	26.9b	1.3d	20.9b	79.2d	383c	5,690c	1.42a	7.81a	2d
5.0	113a	13.1bc	126a	143c	82.8a	392c	1,600b	32,100b	0.93b	7.75b	31.6c
8.4	105a	19.9ab	125a	263b	86.6a	521bc	2,000b	42,800b	0.78c	7.7b	62.2b
9.7	98a	24.2a	122a	330b	81.1a	568ab	2,210b	47,000b	0.74c	7.65c	61.6b
15.3	105a	28.7a	134a	510a	81.2a	767a	3,070a	73,100a	0.7c	7.65c	88.5a
Analysis of variance (Pr > F)											
Rate of USM	0.32	0.07	0.61	0.73	0.99	0.87	0.83	0.71	0.64	0.4	0.12
Runoff rate	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Rate of USM × runoff rate	0.46	0.07	0.48	0.71	0.47	0.89	0.97	0.68	0.21	0.7	0.49

Notes: USM = unconsolidated surface materials. DP = dissolved phosphorus. PP = particulate phosphorus. TP = total phosphorus. NO_3-N = nitrate nitrogen. NH_4-N = ammonium nitrogen. TN = total nitrogen. Cl = chloride. TDS = total dissolved solids. EC = electrical conductivity. Values followed by different letters are significantly different at the 0.05 probability level based on the least significant difference test.

Figure 2

Rate of loss of nitrate nitrogen (NO_3-N) in runoff as affected by runoff rate.

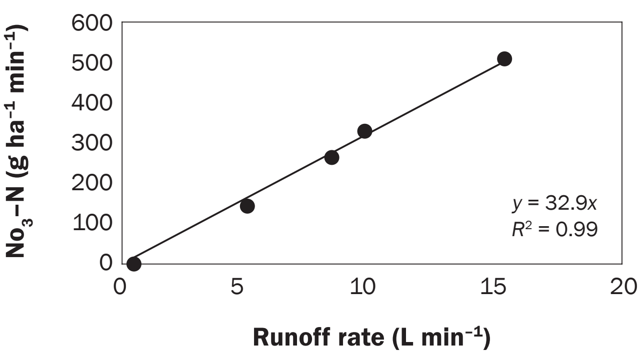
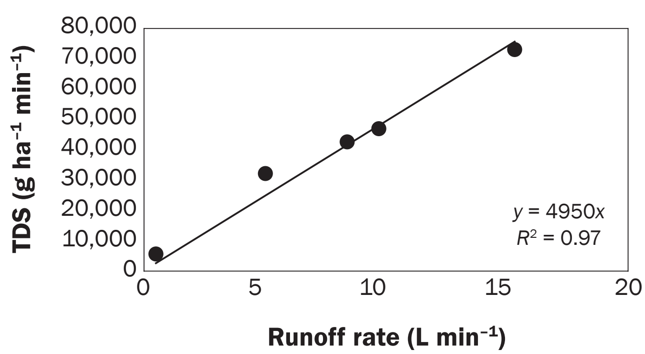


Figure 3

Rate of loss of total dissolved solids (TDS) in runoff as affected by runoff rate.



to 0.57 lb ac^{-1} min^{-1}) and 79.2 to 767 g ha^{-1} min^{-1} (0.089 to 0.86 lb ac^{-1} min^{-1}), respectively (table 4 and figure 2). The regression equation shown in figure 2 was derived for flow rates varying from 0.5 to 15.3 L min^{-1} (0.13 to 4 gal min^{-1}) and should be used with care for flow rates outside of this range. The constraint in this system appears to be the nutrient load capacity for N. It does not appear that nutrient load capacity for N was exceeded for the existing experimental conditions.

The nutrient load rates for NH_4-N varied from 20.9 to 86.6 g ha^{-1} min^{-1} (0.023 to 0.097 lb ac^{-1} min^{-1}) (table 4). No significant differences in nutrient load rates for NH_4-N were found for runoff rates 5 L min^{-1} (1.3 gal min^{-1}) and larger.

Both Cl and the primary constituents that comprise TDS appear to be readily dissolved since the runoff load rates for Cl and TDS increased in a linear fashion with flow rate and varied from 383 to 3,070 g ha^{-1} min^{-1} (0.429 to 3.44 lb ac^{-1} min^{-1}) and 5,690 to 73,100 g ha^{-1} min^{-1} (6.37 to 81.9 lb ac^{-1} min^{-1}), respectively (table 4 and figure 3). The regression equation shown in figure 3 was derived for flow rates varying from 0.5 to 15.3 L min^{-1} (0.13 to 4 gal min^{-1}).

Measurements of EC consistently decreased with flow rate and varied from 0.7 to 1.42 dS m^{-1} (0.23 to 0.47 mho ft^{-1}). No significant differences in EC values were found among the three largest runoff rates. Dilution resulting from increased flow is thought to be the reason for the decrease in EC with flow rate.

Significant differences in soil loss rates were found among inflow increments with values ranging from 2 to 8.85 kg ha^{-1} min^{-1} (2.2 to 9.91 lb ac^{-1} min^{-1}). The increase in soil loss rate with flow rate is well established. Gilley et al. (1987) measured runoff rate, runoff velocity, sediment concentration, and soil loss rates at selected down-slope distances on plots with varying amounts of sorghum and soybean residue. Soil loss rate was also found by Gilley et al. (1987) to increase with flow rate.

Summary and Conclusions

No significant differences in nutrient losses in runoff were found among the treatments containing varying amounts of unconsolidated surface materials. Measurements of DP, PP, TP, NH_4-N, Cl, TDS, EC, and erosion consistently decreased during the three rainfall simulation runs, and each of these parameters was significantly greater during the initial than the third rainfall simulation event. Runoff losses of NH_4-N, TN, and NO_3-N were all correlated to easily obtained soil EC measurements. Each of the water quality parameters was significantly influenced by runoff rate. Thus, runoff rate and not the amount of unconsolidated surface materials on the feedlot surface was the principal variable influencing nutrient losses. Therefore, the frequent removal of unconsolidated surface materials from feedlot surfaces would not be expected to significantly reduce runoff nutrient losses.

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